

ESTIMATES OF THE INTENSITY OF TURBULENCE IN THE
ATMOSPHERES OF MARS AND VENUS

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16. Abstract <p>The levels of velocity, temperature and refractive index fluctuations are estimated for the atmospheres of Mars and Venus on the basis of free-convection and dynamic models. The first model provides the average turbulence dissipation rate and the rate of equalization of temperature gradients by assuming that the lower portion of the atmosphere is subject to convective mixing. The second model is based on an analysis of the global influx of solar energy, with an estimate of the portion that is converted to generate kinetic motions in the atmosphere. According to both models, the velocity fluctuations are several times higher on Mars and lower on Venus than on Earth. The two models provide different levels of temperature fluctuations, and the possible reasons for this are explored.</p>			
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ESTIMATES OF THE INTENSITY OF TURBULENCE IN THE
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The possible rates of fluctuations of velocity and temperature in the atmospheres of Mars and Venus can be estimated in two ways. First it is reasonable to assume that the lower part of the atmospheres of these planets, at least by day, experiences convective mixing. Then, assuming that the turbulent heat flow q_t in free convection comprises a certain fraction of the value $q(1 - A)$, where q is the solar constant for the planet and A is its albedo, the average rate of dissipation of energy ϵ of turbulence and the rate of equalization of the measure of temperature inhomogeneities N can be determined according to the following equations:

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$$\epsilon = \frac{g}{T_0} \frac{q_t}{\rho_0}, \quad (1) \quad N = C \left(\frac{g}{T_0} \right)^{-1/2} z^{-1/2} \left(\frac{q_t}{\rho_0} \right)^{1/2}. \quad (2)$$

Here g is the acceleration of gravity; c_p is enthalpy at constant pressure; T_0 and ρ_0 are temperature and density near the lower boundary of the atmosphere; z is altitude; C is a numerical factor of the order of unity. If ϵ and N are known it is possible with the following general equations to determine the structural functions of the fluctuations of velocity and temperature -- the mean squares of the differences of these values at two points, separated from each other by distance r :

$$D_v(r) = \overline{(\Delta v)^2} = C_1^2 \epsilon^{2/3} r^{2/3} = C_1^2 \epsilon^{2/3}, \quad (3)$$

$$D_T(r) = \overline{(\Delta T)^2} = C_2^2 N \epsilon^{-1/3} r^{2/3} = C_2^2 \epsilon^{1/3}, \quad (4)$$

where C_1 and C_2 are the numerical factors of the order of unity.

On the other hand the values of ϵ were estimated [2] by analyzing the global influx of solar radiation and the possible fraction of it which is converted to the rate of generation (and dissipation in the steady-state case) of kinetic energy in the atmosphere. Also presented in the cited work is the procedure for estimating the N values for large-scale atmospheric motions. It

*Numbers in the margin indicate pagination in the foreign text.

is helpful to use the values ϵ and N thus obtained for estimating the rate of local turbulence. In the case of the earth's atmosphere this approach to the problem gives the correct values in terms of the order of magnitude. Therefore, instead of the model of free convection we will use the second model, which may be called dynamic. The ϵ and N values for the atmospheres of Mars and Venus have been evaluated with the aid of this model [2]. Fluctuations of velocity and temperature occur because of hydrodynamic instability of global atmospheric motions and because of horizontal inhomogeneity of the temperature field.

Temperature fluctuations play the major role in fluctuations of the refractive index, both for light waves and for radio waves in the centimeter and decimeter bands. The dependence of the refractive index n on density for $|n - 1| \ll 1$ is of the form $n = 1 + \alpha \rho$, where α is determined only by molecular composition and depends little on frequency (beyond the absorption lines). This formula may also be written as $n = 1 + \beta p/T$. For carbon dioxide gas, when $p = 1$ atm and $T = 273^\circ\text{K}$, $n = 1.00045$ [3], and thus $\beta = 0.123$ deg/atm. A value close to this is also valid for the decimeter band. We point out by way of comparison that $\beta = 0.079$ deg/atm ($\lambda = 0.5 \mu$) for air. Fluctuations of n are determined by the equation $\delta n = -\beta \frac{p}{T} \frac{\delta T}{T}$, since pressure fluctuations are negligible here [4]. If temperature fluctuations are described by the 2/3 law, /395 expressed by the formula presented in [4], then the same law will be valid for the refractive index, and the corresponding structural characteristic C_n will be

$$C_n = \beta \frac{p}{T} \frac{C_T}{T}. \quad (5)$$

The structural characteristics of the fluctuations of velocity, temperature and refractive index are presented in the table for the two models of the atmospheres of Mars and Venus, the parameters of which are presented in [2]. The relative values of these characteristics are presented for clarity in comparison with their corresponding values for the earth's atmosphere. The properties with the superscript 1 pertain to the free convection model at a given altitude above the surface of the planet, and the properties with the superscript 2 apply to the dynamic model. In calculations according to the free convection model it was assumed that the fraction of turbulent heat flow q_t of the influx of solar energy per unit of area of the surface $q(1 - A)$ is

identical in the atmospheres of earth, Mars and Venus (in the earth's atmosphere $q_t/q(1 - A)$ is of the order of 0.1 or less). It is assumed here that for the earth $T_0 \approx 300^\circ\text{K}$, $\rho_0 = 1.2 \cdot 10^{-3} \text{ g/cm}^3$, $c_p = 0.24 \text{ cal/g deg}$; for Mars $T_0 = 250^\circ\text{K}$, $\rho_0 = 2 \cdot 10^{-5} \text{ g/cm}^3$ (CO_2 at surface pressure $p_0 = 5 \text{ mb}$; if $p_0 = 13 \text{ mb}$, then the density is correspondingly higher), $c_p = 0.2 \text{ cal/g deg}$, $g = 370 \text{ cm/s}^2$; for Venus (the deep model) $T_0 = 700^\circ\text{K}$, $\rho_0 = 0.07 \text{ g/cm}^3$, $g = 885 \text{ cm/s}^2$, $c_p = 0.28 \text{ cal/g deg}$. For the second model of the atmosphere of Venus $p_0 = 20 \text{ atm}$, $T_0 = 550^\circ\text{K}$, $\rho_0 = 0.02 \text{ g/cm}^3$.

Planet	p_0	$c_p^{(1)}$	$c_p^{(2)}$	$c_T^{(1)}$	$c_T^{(2)}$	$c_u^{(1)}$	$c_u^{(2)}$
Mars	5 mb	3	4	20	2	0.15	0.05
	13 mb	4	2	10	1.5	0.2	0.02
Venus	100 atm	0.15	0.2	0.07	9	2	250
	20 atm	0.3	0.3	0.15	5	1	40

The data in this table indicate that the fluctuations of velocity, according to both models, is several times greater on Mars, and several times less on Venus than in the earth's atmosphere. The situation is different in the case of temperature fluctuations. In the case of the convective model temperature fluctuations are approximately an order of magnitude weaker for Venus and an order of magnitude stronger in the atmosphere of Mars than in ours. This is the result of the very different thicknesses of the atmospheres with almost the identical amount of heat reaching the surfaces of all three planets¹. The dynamic model says that the temperature fluctuations of Venus are almost an order of magnitude greater than in the earth's atmosphere, and of the same order of magnitude (somewhat greater) on Mars. Again this difference is related to sharp differences in the thicknesses of the atmospheres. In the thin atmosphere of Mars, even in the presence of strong global processes, convection plays the predominant part in the development of temperature fluctuations. In the thick atmosphere of Venus convection cannot play an important role, and temperature fluctuations occur only during global mixing of the atmosphere,

¹If no visible radiation reaches the surface of Venus and part of it is absorbed by the atmosphere, then the turbulent heat flow will be less than the value used here. Therefore the figures presented in the table according to the convective model should be regarded as possible top estimates.

which is considerably colder at the poles. A reduction of the surface temperature of Venus toward the poles is indicated by the unique findings of A. D. Kuz'min and B. Clark [5]. It is noteworthy that because of the smallness of turbulent heat flows the vertical temperature gradient in the lower part of the atmosphere of Venus should be close to adiabatic. /396

Fluctuations of the refractive index on Mars are approximately one order of magnitude smaller than in the earth's atmosphere. On Venus, according to the convective model, they are about the same as ours, and according to the dynamic model, approximately two orders of magnitude stronger. Only experiments will tell which model is correct.

Let us evaluate the possible fluctuations of the strength of a radio signal, transmitted from the depth of the atmosphere of the planet to the earth. On the basis of the theorem of mutuality it can be asserted that the relative fluctuations of the amplitude of a signal, radiated by an antenna from the atmosphere of the planet and received on earth, will be equal to the fluctuations in the same system, but in which the transmitting and receiving antennas are mutually substituted. For the transmitting antenna, located on the earth, the wave received on the planet may be assumed plane, and to calculate fluctuations of the signal level we may use the equation [4]

$$\chi^2 = \sigma_x^2 = \left(\ln \frac{1}{1 - \sigma_x^2} \right)^2 = 0.64 k^2 \int_{z_0}^z C_n^2(z) z^2 dz, \quad (6)$$

where $k = 2\pi/\lambda$ is the wave number; z_0 is the elevation of the transmitter above the surface of the planet. In the case of free convection we may write

$$C_n^2(z) = C_n^2(z_0) \left(\frac{z_0}{z} \right)^4 \exp \{-2(z - z_0)/H\}, \quad (7)$$

assuming that C_n decreases with altitude basically in proportion to pC_t (H is the altitude of a homogeneous atmosphere). Substituting this equation into (6) for $\lambda = 30$ cm and assuming that the characteristic value of C_n^2 at altitude $z_0 = 1$ m in the earth's atmosphere is $10^{-14} \text{ cm}^{-2/3}$ [6], we find that in the atmosphere of Venus $\sigma_x \approx 10^{-4} - 10^{-5}$ in the assumption that the measurements of "Venera-4" were completed near the surface of the planet. The same value is

also obtained on the assumption that the measurements were completed at approximately 20 km from the surface. Here $H \approx 10$ km. For calculations according to the second model it is necessary to know the characteristic C_n^2 for the earth's atmosphere. Calculation according to the dynamic model, using $N = 10^{-3}$ deg/s and $\epsilon = 4$ cm²/s³ [2] yields $C_n^2 \approx 10^{-15}$ cm^{-2/3}. A summarization of C_n^2 , measured by different methods under different conditions, is presented in review [6]. For a free atmosphere these values vary within the range of 10^{-15} - 10^{-17} cm^{-2/3}, and in the surface layer they go up several units to 10^{-14} cm^{-2/3}. Therefore we will use as the characteristic value for the earth $C_n^2 = 10^{-15}$ cm^{-2/3}, bearing in mind that all the ensuing estimates may give us an idea only of the possible orders of magnitudes of the fluctuations of signal strength.

Assuming $p_0 = 20$ atm, then using equation (6) for $\lambda = 30$ cm we obtain $\overline{\chi^2} \approx 0.02$, whence $\sigma_\chi \approx 0.14$. We also obtained the same value using the deep atmosphere model, assuming that $C_n^2(z)$ decreases with altitude by analogy with (7), but without the factor $(z_0/z)^{2/3}$. The experimental value of σ_χ , according to [7], is 0.18 ± 0.05 . This value is 3-4 orders of magnitude greater than the one given by convection and agrees with estimates according to the dynamic model.

Additional Comments

By September 1969 new data were compiled and new theoretical findings were obtained. The Soviet unmanned space vehicles "Venera-5" and "Venera-6" confirmed that surface pressure is of the order of 100 atm. Noteworthy among other data are those of Berdzh, whose preliminary findings are published in this collection (p. 355). It follows from this work that the temperature distribution in the atmosphere of Venus is homogeneous and there is no perceptible temperature difference between the equator and the poles. This contradicts data [5], on which were based all the estimates of ϵ and N presented in [2]. The theorem of similarity of global motions of planetary atmospheres [8] can be used for evaluating ϵ , N and δT -- the equator-pole temperature difference on the basis of purely external data: influx of solar heat into the atmosphere, its enthalpy and pressure, and the radius of the planet, whereas in [2] the δT values had to be known beforehand. The estimates

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of δT , presented in [8] for Venus, give values only of the order of several degrees, which agrees with Berg's findings. Consequently the ϵ values computed here by the "dynamic method" must be reduced by two orders of magnitude, i.e., the $C_v^{(2)}$ values are approximately five times smaller. The $N^{(2)}$ values must be decreased by four orders ($N \sim (\delta T)^2$ [2], and therefore $C_r^{(2)} \sim N^{1/2} \epsilon^{-1/6}$ (and $C_n^{(2)}$) for Venus are decreased by approximately 200-fold. As a result it is not necessary to be concerned with the agreement between the above estimates of σ_x and the data presented [7]. Detailed analysis of the data on fluctuations of the amplitudes of radio signals from unmanned space vehicles "Venera-4" and "Mariner-5" [7, 9], presented in [10], revealed a considerable discrepancy between these two series of data. Estimates of σ_x^2 , based on theory [8], give values close to the observed data [9, 10] (see [11]).

REFERENCES

1. Obukhov, A. M., *Izv. AN SSSR, Seriya Geofiz.*, No. 9, 1960.
2. Golitsyn, G. S., *Izv. AN SSSR, Fizika Atmosfery i Okeana*, Vol. 4, No. 11, 1968.
3. Chaylds, U., *Fizicheskiye Postoyannyye* [Physical Constants], Fizmatgiz Press, 1962.
4. Tatarskiy, V. I., *Rasprostraneniye Voln v Turbulentnoy Atmosfere* [Electromagnetic Propagation in Turbulent Atmosphere], "Nauka" Press, 1967.
5. Kuz'min, A. D. and B. J. Clark, *Astron. Zh.*, Vol. 42, No. 4, p. 595, 1965.
6. Tatarskiy, V. I., *Izv. Vyssh. Uch. Zav., Radiofizika*, Vol. 3, No. 4, 1960.
7. Kolosov, M. A., O. I. Yakovlev and A. I. Yefimov, *Dokl. AN SSSR*, Vol. 182, No. 1, 1968.
8. Golitsyn, G. S., *Dokl. AN SSSR*, Vol. 190, No. 2, 1970.
9. Kliore, A., G. S. Levy, D. L. Cain, G. Fjeldbo and S. I. Rasool, *Science*, Vol. 158, p. 1683, 1967.
10. Gurvich, A. S., *Izv. AN SSSR, Fizika Atmosfery i Okeana*, Vol. 5, No. 11, 1969.
11. Golitsyn, G. S. and A. S. Gurvich, *J. Atmosph. Sci.*, Vol. 28, No. 1, 1971.

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